

Resonance

by Joshua Martin

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Electronics - Resonance



Abstract

The purpose of this report is to determine the and compare the Q factor and resonant frequency of a series RLC circuit for a simulated and real circuit. The key points noted are that the basic theory value and graphical value for Q factor were very different. This concluded to be a result of the basic theory method ignoring all components except R, L and C. However this did not reflect to the resonant frequency value, this value was nearly the same for both the simulation and real circuit. It was also concluded that the reason the voltage of the real circuit never returned to its initial value, is because there would have been some energy lost through the circuit as heat. Therefore in conclusion, to calculate Q factor, it is better to do it graphically as it is a real representation of what actually happened in the circuit.



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Electronics Assignment – Resonance

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1 Introduction

1.1 Background info

1.1.1 Electronics

Firstly, to understand resonance in electronics, electricity must be understood at its most basic level. Electricity is formed from the flow of electrons, much like the flow of water through a pipe. A reservoir (cell) stores the potential energy (voltage 'V') for the system and releasing the water (electricity) through the pipe is what's called the flow rate. For electricity, flow rate is measured in coulombs over a defined period of time, however that is not commonly used. This flow rate is called the current and it is measured in Amps while being given the symbol 'I'. The final part of this basic principle is resistance (Ω), any substance that electricity passes through has some form of resistance to the electron flow

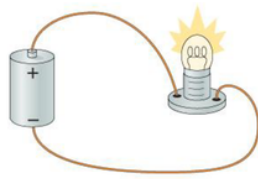


Figure 2 [8] lightbulb circuit

[1]. A lightbulb for example, has a coiled filament that acts as the resistor in this circuit 'Figure 1'. The filament resists the current supplied by the battery and limits the amount of current allowed to flow through. In more complex circuits, there are purpose-built resistors to control the amount of current flowing through. If there is a sudden surge of current, then it may overpower the resistor and cause it to fail, this is the principle of a lightbulb failing.

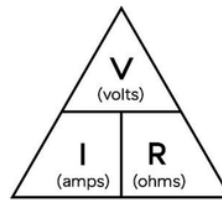


Figure 1 Ohms Law [9]

$$V = I \times R$$
$$I = \frac{V}{R}$$
$$R = \frac{V}{I}$$

The key points explained above represent a fundamental principle of electronics, Ohms Law. This is the relationship between Voltage, current and resistance, expressed as $V = I \times R$. This equation can be transposed to find the subject using the triangle in Figure 2.

Ohms Law – the current through a conductor is directly proportional to the voltage across it. [2]

1.1.2 Proteus

During this report, the electronics simulation software proteus is used. Both to demonstrate an RLC series circuit and to compare with a real life practical RLC circuit. Using this software, you can create complex circuits that replicate those that will be used in real life, with the ability to change the values of each component it can give an accurate computer-generated representation.

1.1.3 Experimental

The experimental part of this report uses simple electronic circuit making components such as a breadboard, resistor, capacitor, inductor, oscilloscope, probe, signal generator and a selection of wires. The purpose is to build a series RLC circuit and use the signal generator to determine what the resonant frequency of the circuit is.

1.1.4 Series Circuits

Series circuits are defined by the fact that the flow of electricity only has one path to take around the circuit. All of the components in the circuit will follow on from one another in a linear fashion. As opposed to parallel circuits where the electricity may have a choice of paths to take in the circuit before ultimately arriving at the same final destination.

1.1.5 RLC circuits

An RLC circuit, in this case a series RLC circuit, consists of a resistor, inductor and a capacitor all in the same circuit one after the other.

1.2 Resonance

1.2.1 Definition

Series resonance occurs in an RLC circuit when the inductive reactance of the inductor, and the capacitive reactance of the capacitor are equal in magnitude and therefore cancel each other out. This can also be written as $X_L = X_C$. [3]

1.2.2 Application

Electrical resonance is commonly used in tuning for radio stations. The tuner's job is to use the principle of resonance to extract a certain frequency from the air, and translate it into sound through the radio. When changing the frequency of the radio, you are changing the point that the circuit resonates at. For example, changing the frequency of the radio to 97.4FM, translates into the tuner resonating at a frequency of 97.4MHz. As the tuner is resonating at this frequency, it is ignoring all other frequencies in the air and will only pick up the signals being sent over this frequency. The radio's job is to then translate the signals being received over this frequency into sound.

Another use for a series resonant circuit is for energy harvesting from radio frequencies. In the same way that the tuner picks up the radio frequency and converts it into sound, this application will be picking up the radio frequency and converting it into energy. This could be used for charging phones and similar small wearable electronic devices. The results of this investigation [4], verify that energy can successfully be transferred from the harvester to the cell phone if it's within 3cm. It was also noted that the quality factor of the components is critical for the adequate operation of the circuit.

1.3 Basic Theory

The first law for basic theory is Ohm's law, as explained in section '1.1.1'.

Within an AC circuit, reactance is the opposition of the change of flow of current within a circuit.

Reactance can be separated for certain components, there is capacitive reactance of the capacitor, and inductive reactance of the inductor, both instances are measured in Ohms. [2]

$$\text{Capacitive reactance } (X_C) = \frac{1}{2\pi fC}$$

Capacitors store voltage as an electric charge on two plates separated by a dielectric. To remove the charge from a capacitor, there must be work done, meaning that it cannot happen instantly, and it adds AC resistance to the circuit.

$$\text{Inductive reactance } (X_L) = 2\pi fL$$

Inductors are made up of a coil of wire and use a magnetic field to store electrical energy. To change the strength of the magnetic field then the current flowing through the inductor must be changed. [2]

To calculate the total reactance in a circuit that contains an inductor and a capacitor, you must consider the phase of the circuit. A pure capacitor and pure inductor cause a 90° phase shift in opposite directions, therefore the total reactance for the circuit is as follows.

$$X_T = X_L - X_C$$

1.4 Q Factor explanation and equations

The Q factor is a dimensionless value that gives a measure of quality of a resonant circuit. A higher value for the Q factor corresponds to a narrow bandwidth; this is desirable in many applications. [5]

To relate back to the previous application for resonance, if you have a high Q tuned circuit operating as a radio, then although it would be more difficult to tune, it would in fact be much better at filtering out signals from nearby frequencies. For a radio station this is highly desirable, as any interference from other radio stations will overlap the frequency that is desired.

In this report, the Q factor will determine the quality of the components creating the circuit, from the simulated circuit which should have an ideal Q factor, and the real circuit which may vary due to basic wear and tear among other factors.

To measure Q factor graphically, you must find the value for the bandwidth at half power. Half power for the circuit is at 70.7% or 3dB below the maximum. [6]

Once the bandwidth is found, then use $Q = \frac{F_r}{BW}$

To find the Q factor using mathematical methods, there are a range of methods to do this, however for this purpose we will use the component values.

Therefore $Q = \frac{1}{R} * \frac{\sqrt{L}}{C}$

2 Method

2.1 Simulation

Using proteus software, as discussed previously, a series RLC circuit was created using the components available in the software.

Resistor – select from the components mode and set the value to 3.3Ω

Capacitor – select from the components mode and set the value to $1\mu F$

Inductor – select from components mode and set the value to $1mH$

Signal Generator – select from the instrument's mode

Oscilloscope – select from the instrument's mode

Ground – select from the terminal's mode

Once you have got all of these components onto the screen, start connecting the components to each other as shown in the diagram below.

Pressing the play button on the simulation will open up the signal generator dials and the oscilloscope.

Create an excel table with frequency values that will be used to measure the voltage going through the circuit, more readings should be taken around the point of likely resonant frequency which will be $5kHz$.

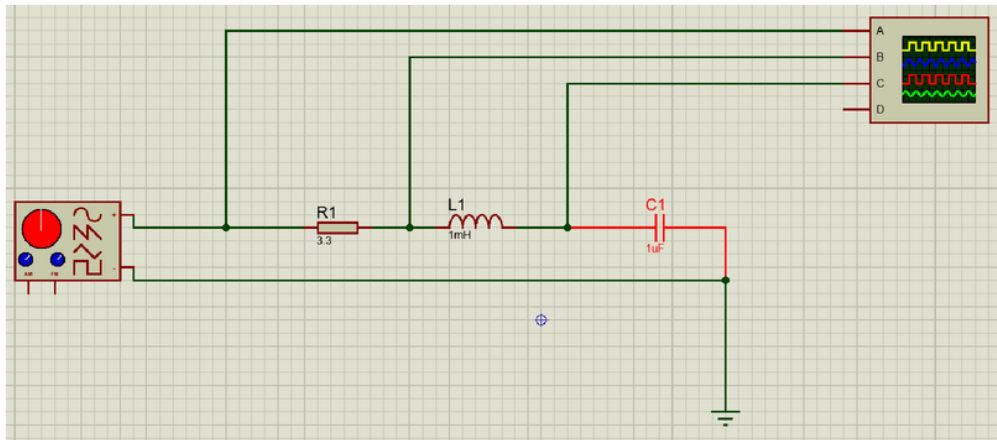


Figure 3 Proteus Circuit

When the signal generator and oscilloscope controls have opened, use them to adjust the frequency so that it matches the values stated in the excel table, to achieve the higher frequencies you must use the multiplication dial.

Take a voltage reading at each frequency and input to the excel table, once all of the values have been recorded, create a graph to visually show the results.

2.2 Experimental

To create the circuit in the lab, components with the same values were used to give the circuits a fair chance for comparison. However, some extra wires and connectors are required. These come in the form of a breadboard to form the base of the circuit, and a selection of wires to connect the components to the larger banana wires, into the signal generator.

First, once you've understood how the breadboard works, connect the resistor, then the inductor, and then the capacitor into the breadboard. Once you have created your circuit board, connect the probe to the input leg of the capacitor and then connect the signal generator and turn the oscilloscope on.

To conduct the experiment, set up a table in Microsoft excel stating values between 100Hz to 20,000Hz. Choose values closer together around the point where resonant frequency is likely to occur, this will be at roughly 5kHz.



Use the signal generator to alter the frequency being sent into the circuit, getting the display as close as possible to each value in the excel table. For each frequency, measure the voltage that is being picked up by the probe. This can be done by counting the squares of the amplitude on the wave using the oscilloscope or setting the oscilloscope to show you the value it has calculated itself. If counting the squares, ensure that the correct value is being calculated as one square may equal 2 volts.

When calculating manually, you should manipulate the oscilloscope to ensure you are getting the most accurate reading possible. This can be done by first changing the Volts/division dial, this will increase or decrease the size of the sine wave and make it easier to count the grid accurately, or to fit the sine wave into the screen.

Also, the vertical position should be changed on the oscilloscope manually, this is to move the lowest peak of the sine wave, so it just touches one of the grid lines. This will give the best chance of counting the squares more accurately.

Once all the voltage values have been recorded for each frequency, create a graph to visually show the results, from this graph you can see where resonant frequency occurs, and we can also work out the Q factor graphically. To work out the Q factor graphically you must work out the bandwidth

3 Results

3.1 Component Measurements

Resistor	Inductor	Capacitor
Stated Value – 3.3Ω	Stated value – 1mH	Stated value - 1μf
Measured Value – 2.89Ω	Measured Value – 0.977 mH	Measured value – 1.013μf
Measured inductance – 13.7μf	Series resistance – 2.8Ω	

3.2 Resonant Frequency Graphical

Frequency	XC	XL	XT
100	1591.546	0.62832	1590.917389
200	795.7729	1.25664	794.5162146
500	318.3091	3.1416	315.1675418
1000	159.1546	6.2832	152.8713709
2000	79.57729	12.5664	67.01088546
4500	35.36768	28.2744	7.093282427
4600	34.59882	28.90272	5.696099765
4700	33.86267	29.53104	4.331634664
4800	33.1572	30.15936	2.997842275
4900	32.48052	30.78768	1.692844677
5000	31.83091	31.416	0.414914184
5100	31.20678	32.04432	-0.837541388
5200	30.60665	32.67264	-2.065991746
5300	30.02916	33.30096	-3.271795676
5400	29.47307	33.92928	-4.456211311
5500	28.93719	34.5576	-5.620405287
10000	15.91546	62.832	-46.91654291
20000	7.957729	125.664	-117.7062715



Figure 4 Reactance Simulation values

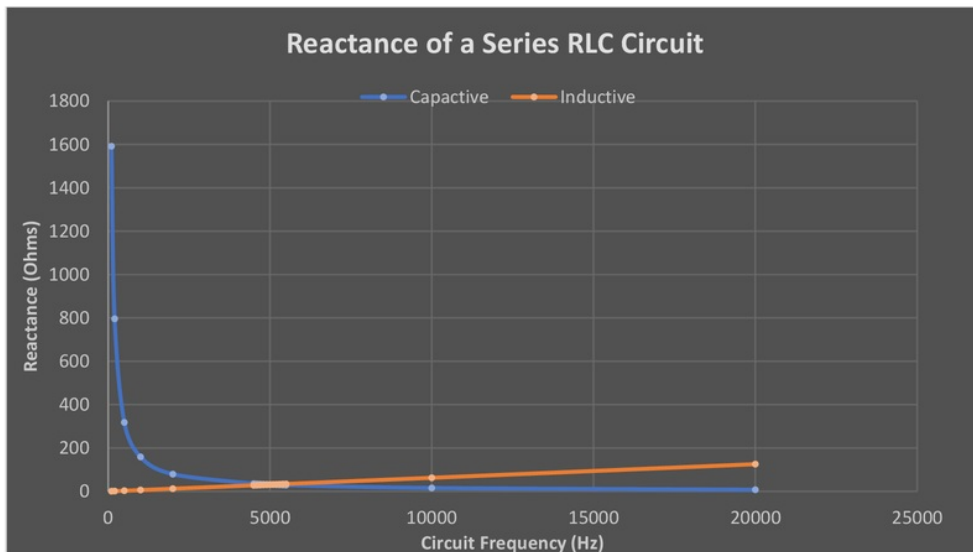


Figure 5 Reactance Curve

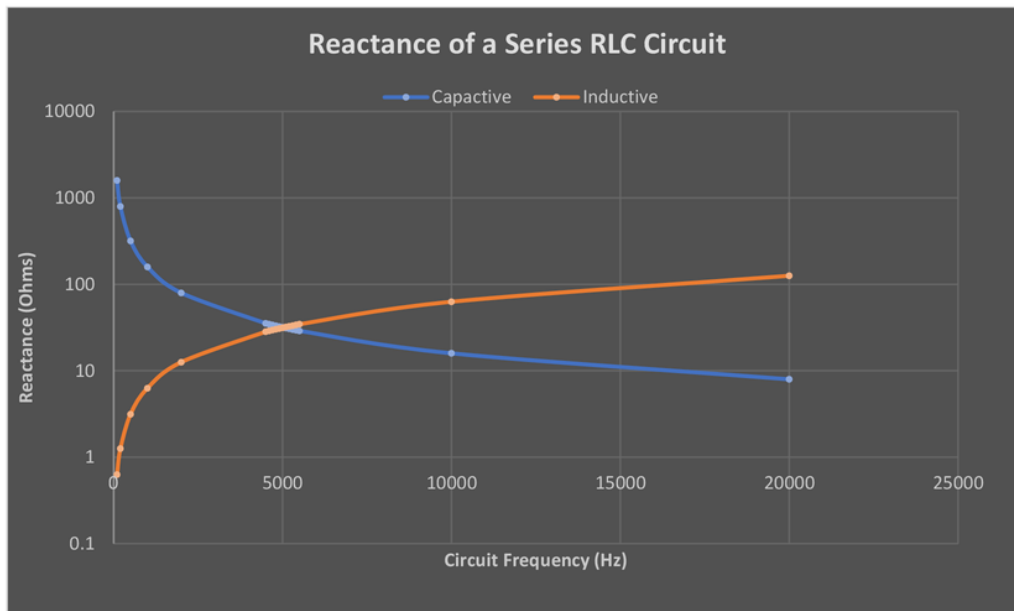


Figure 6 Reactance Curve logarithmic

Using basic theory, the resonant frequency was calculated using both the graphical and mathematical methods.

Figure 5 shows how the capacitive reactance follows a curve, however the inductive reactance is a straight line. Although due to the large difference in values, figure 7 shows the same results with a logarithmic scale to make it easier to understand. This is because it separates the measurement points equally on the graph instead of spaced out unevenly.

As shown in the table above, the capacitive and inductive reactance were calculated using the equations stated previously in 1.3. By plotting these results for X_C and X_L on the graph, you can see where the point of resonant frequency is. This point is where the two lines intersect, and it is shown to be around the 5000Hz Mark.

3.3 Mathematical

It is also possible to work out the resonant frequency in a purely mathematical method, using the values of the components being used.

$$\text{Resonant Frequency} = \frac{1}{2\pi\sqrt{LC}}$$

Where:

L = Inductance @ 1mH

C = Capacitance @ 1uF

Therefore:

$$1/(2\pi\sqrt{(1 * 10^{-3})(1 * 10^{-6})})$$

Resonant Frequency = 5032.92 Hz

3.4 Simulation

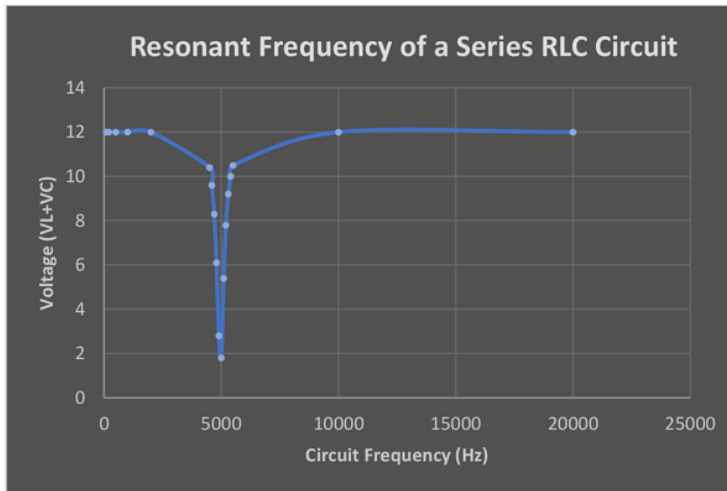


Figure 7 resonant frequency simulation

The graph above shows the results from the Proteus simulated RLC circuit. This backs up the previous statement that the resonant frequency is around the 5000Hz point.

Frequency	VL+VC
100	12
200	12
500	12
1000	12
2000	12
4500	10.4
4600	9.6
4700	8.3
4800	6.1
4900	2.8
5000	1.8
5100	5.4
5200	7.8
5300	9.2
5400	10
5500	10.5
10000	12
20000	12

3.5 Experimental

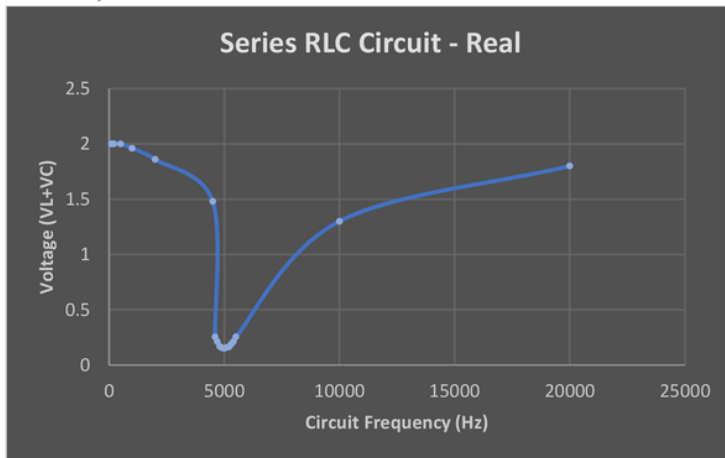


Figure 8 resonant frequency real

Although the voltage used for the experimental circuit was difference, the behavior would be the same. This graph also shows that the point of resonant frequency is around 5000Hz.

Frequency	VL+VC
100	2
200	2
500	2
1000	1.96
2000	1.86
4500	1.48
4600	0.254
4700	0.212
4800	0.17
4900	0.156
5000	0.15
5100	0.16
5200	0.164
5300	0.188
5400	0.212
5500	0.254
10000	1.3
20000	1.8

3.6 Q Factor Basic theory

To work out Q factor for this circuit, the perfect values for the passive components were used, this is a representation of what the simulations Q factor should be, the equation for this is as follows:

$$Q = \frac{1}{R} \left(\frac{\sqrt{L}}{C} \right)$$

Therefore in this circuit $Q = \left(\frac{1}{3.3} \right) * \sqrt{(1 * 10^{-3}) / (1 * 10^{-6})}$

$$Q = 9.58$$

However, the real measured values of the components were slightly different :

Resistor = 2.89Ω

Inductor = 0.977mH

Capacitor = 1.013uF

Substituting these values into the same equation above

$$Q = 10.75$$

3.7 Q Factor Graphical

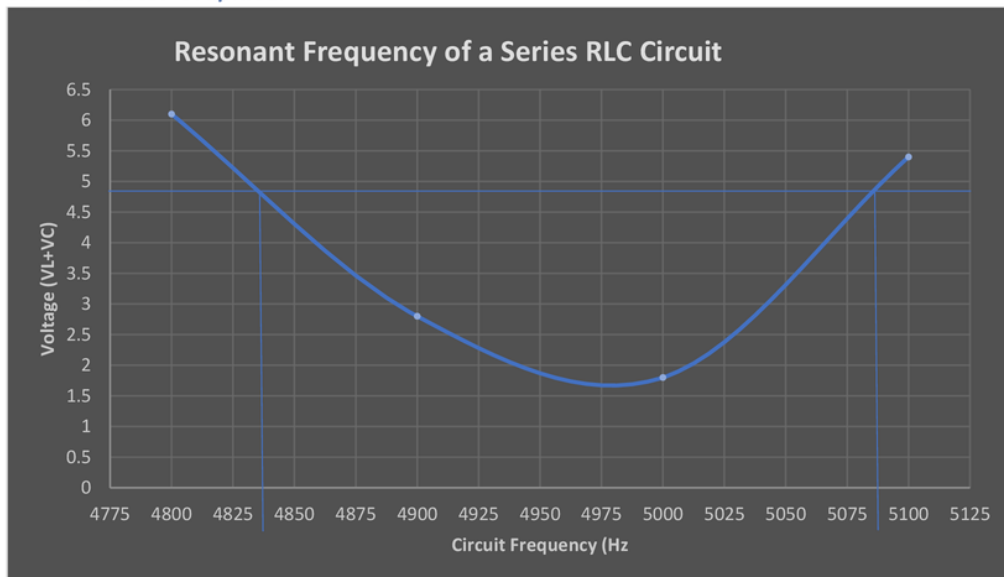


Figure 9 bandwidth for simulation

The graph above shows the point of resonant frequency zoomed in so that the bandwidth can be determined.

The two frequencies here have been worked out to be 4837.5Hz and 5087.5Hz

To calculate Q factor from this, the equation $Q = \frac{Fr}{BW}$ is used. [6]

The bandwidth is calculated as 5087.5 – 4837.5 = 250Hz

Therefore the Q factor graphically is $5000 / 250 = 20$

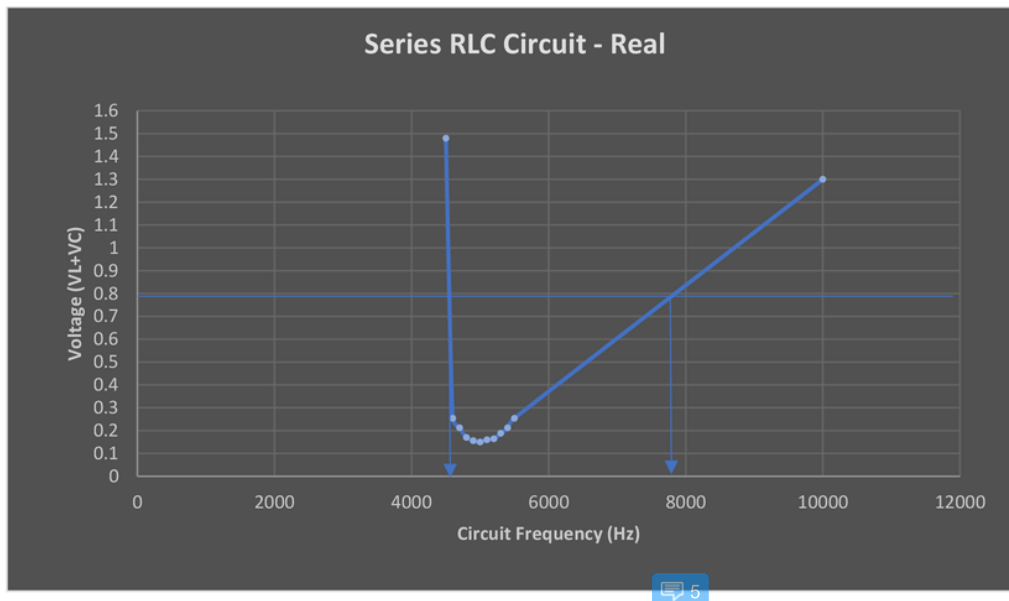


Figure 10 bandwidth for real

With the experimental values, the bandwidth is not as accurate, due to the wider peak over a larger frequency range, however the frequencies for bandwidth have been worked out as 4300Hz and 7800Hz.

Therefore the bandwidth for this circuit is $7800 - 4300 = 3500$

This means that the Q factor will come out as $5000 / 3500 = 1.43$

[7]

4 Discussion

4.1 Resonant Frequency graphical

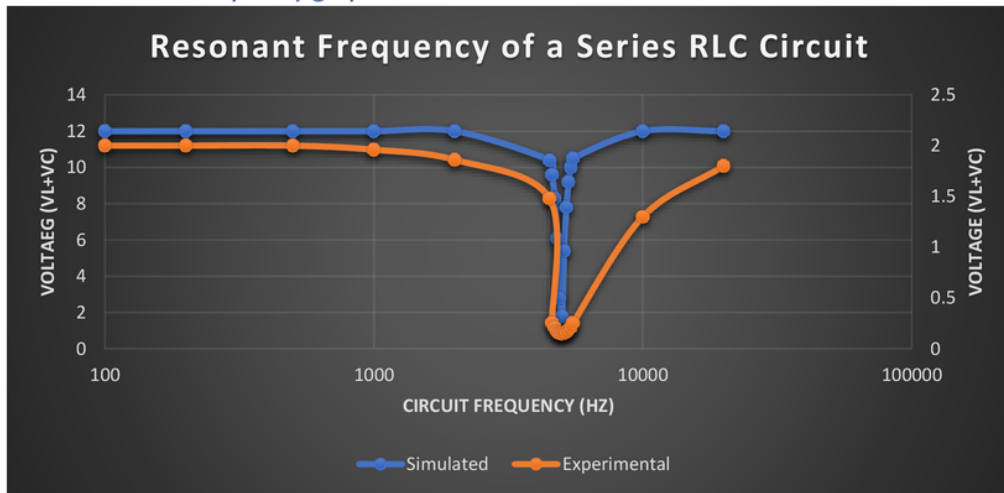


Figure 11 real and simulation comparison graph

This graph shows the two curves displayed previously in one area for an easy comparison.

The key observation with this graph, is that before the point of resonant the curves were looking relatively similar. However, that's where the similarity ended, at the point of frequency, the simulated circuit has shown a much sharper peak than the experimental circuit. This alone proves that the Q factor of the simulated circuit would be a higher value than the real circuit.

This could initially be since the simulation assumes a perfect scenario, such as the components being the same value as stated and there being no energy loss. With a real circuit this isn't the case. The components were measured for their appropriate properties and it was found that all the components we were using had some level of error. These may still be within the tolerances of the components; however, the simulation doesn't take these into account.

Also, the components that were used, are university owned components that have been used for multiple experiments over a few years and there is no doubt that they will have started to wear out and be less efficient to work with.

Lastly on this graph, it's noted that the real voltage never returned to its 100% value unlike the simulation. This will be because some energy is being lost throughout the circuit, often in the form of heat or noise, this is dissipated into atmosphere, so it isn't noticeable by eye, this is the reason heat dissipation solutions are highly important in electronic circuits.

4.2 Resonant Frequency mathematical

The resonant frequency value calculated mathematically, was done for both perfect components and with the measured values. They came in at 5032.92Hz and 5059.04Hz respectively.

These are close values to what has been determined from the graph around the 5000Hz mark, the possible margin of error would come from human error during the experiment that may cause a slight shift to the results, down to the calibration of the equipment we were using.

4.3 Q factor

When calculating the Q factor for the simulation, it was unusual to see that the value gained from the graph was much higher than the value achieved mathematically, as the components are assumed to be perfect then the mathematical and graphical result should have been near enough the same. However, the fact that both Q factors were reasonably high numbers, this was expected due to no error and fatigue of components being considered. A perfect should have a high Q factor, as was proven during this experiment.

The Q factor for the real circuit had the largest difference between the mathematical and graphical values. The Q factor for the measured values still worked out to roughly the same as the Q factor for perfect components at about 10. However, when it came to measure graphically, the Q factor worked out at 1.43. this is dramatically lower than the theoretical value, and this proves that the quality of the circuit, is worse than just the quality of the main components.

5 Conclusion

From this experiment, it has been shown that even when the same circuit is created with components of what should be the same values, a simulation and real experiment can come out with very different values under different conditions.

The main reason for the large difference in Q factor particularly, is due to the age and wear of the components in the circuit. Not only the RLC components, but the wires, breadboard, oscilloscope and signal generator will all have played a part in decreasing the quality of the circuit.

6 References

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Resonance

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

59/100

PAGE 1



Comment 1

Nice abstract. All the information needed is present.

PAGE 2

PAGE 3

PAGE 4

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PAGE 6

PAGE 7



Comment 2

While I did ask for a description of what you have done, you did not need to include a step by step instruction manual. You should assume the reader has a level of knowledge and understands the concepts and methods discussed.

PAGE 8



Comment 3

You have included a graph of this data, you did not need to include a table of it also.

PAGE 9

PAGE 10

PAGE 11



Comment 4

The capacitor value should have been included in the square root. Your equation should read...

$$Q = (1/R) \times (\text{SQRT}(L/C))$$

PAGE 12



Comment 5

I think your first data point on this graph may have been mistyped.

PAGE 13

PAGE 14



Comment 6

How can you back this statement up?

The differences you saw were actually due to the inductor having a DC resistance (caused by the wire in its windings) of a similar value to the resistor, and due to the output resistance of the signal generator effectively adding 50R to the circuit.

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GRADING FORM: SMU GENERIC_SMOSEY

JOSHUA MARTIN

59.30

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied.

3.4

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Knowledge is accurate with a good understanding of the field of study.

16.5

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances.

16.5

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of methods, tools and techniques. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.

19.5

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate well, confidently and consistently in a suitable format. Work is coherent and fluent and is well structured and organised.

3.4